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**An Epoxy, Epoxy System, And Method Of Forming
A Conductive Adhesive Connection**

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1 An Epoxy, Epoxy System, And Method Of Forming
2 A Conductive Adhesive Connection

3 TECHNICAL FIELD

4 This invention pertains to epoxies, epoxy systems, and methods of
5 forming conductive adhesive connections between electrical nodes.
6

7 BACKGROUND OF THE INVENTION

8 Electrical circuits are frequently constructed by adhering
9 components of the circuit to interconnects with conductive epoxy. The
10 conductive epoxy is initially provided in an uncured, and non-conductive
11 form. The epoxy comprises conductive materials, such as metal flakes,
12 which are spaced too far apart in the uncured form of the epoxy to
13 create conductance. As the epoxy cures, it shrinks and the conductive
14 particles come in contact with one another to transform the epoxy into
15 a conductive form. The transformation from a non-conductive form of
16 epoxy to a conductive form occurs gradually over time, rather than as
17 a step function. The epoxy progresses from being non-conductive, to
18 being partially conductive, to being fully conductive over a period of
19 from one to two hours.

20 In some circuits, batteries and integrated circuit chips are
21 physically and electrically interconnected with conductive epoxy.
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1 Unfortunately, during the curing of the epoxy there is a period when
2 the epoxy is partially cured and during which a low current flows from
3 the battery to the chips. The low current can turn the chips "on" at
4 lower than desired current flow. When the chips turn on at such low
5 current flow, there is an undesired battery drain, and, frequently, a
6 "latch-up" of the chips whereby the chips are rendered non-operable.
7 Accordingly, it is desired to develop alternative methods of adhering
8 chips and batteries to substrates whereby the low-current flow is
9 substantially alleviated.

10 11 SUMMARY OF THE INVENTION

12 The invention encompasses epoxies, epoxy systems, and methods
13 of forming conductive adhesive connections between electrical nodes.

14 In one aspect, the invention encompasses a method of forming a
15 conductive adhesive connection. First and second nodes are provided.
16 A liquid conductive epoxy is provided between the first and second
17 nodes. The liquid conductive epoxy has sufficient conductivity that
18 a 15 mil length sample of the liquid conductive epoxy having cross-
19 sectional dimensions of 50 mil by 2 mil has a resistance of less than
20 about 100 ohms along its length while having a viscosity of less than
21 about 100,000 centipoise (cps). The liquid conductive epoxy is cured
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1 to form a conductive adhesive connection between the first node and
2 the second node.

3 In another aspect, the invention encompasses a method of forming
4 a conductive adhesive connection. First and second nodes are provided.
5 A liquid conductive epoxy mixture is provided between the first and
6 second nodes. The liquid conductive epoxy mixture is formed by mixing
7 a first liquid and a second liquid. The liquid conductive epoxy mixture
8 has sufficient conductivity that a 15 mil length sample of the liquid
9 conductive epoxy having cross-sectional dimensions of 50 mil by 2 mil
10 has a resistance of less than about 100 ohms along its length between
11 about 10 minutes and about 20 minutes of mixing the first and second
12 liquids. The liquid conductive epoxy is cured to form a conductive
13 adhesive connection between the first node and the second node.

14 In yet another aspect, the invention encompasses an epoxy system.
15 The epoxy system includes a first liquid comprising a hardener, a second
16 liquid comprising a base epoxy, and a third liquid comprising a
17 concentration of an ionic salt. The first, second and third liquids are
18 configured to be mixed together to form a liquid epoxy which will cure
19 to form a conductive adhesive bond.
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1 BRIEF DESCRIPTION OF THE DRAWINGS

2 Preferred embodiments of the invention are described below with
3 reference to the following accompanying drawings.

4 Fig. 1 is a block diagram of a wireless communication system
5 including an interrogator and a wireless communication device embodying
6 the invention.

7 Fig. 2 is a front elevational view of the wireless communication
8 device.

9 Fig. 3 is a front elevational view of the wireless communication
10 device at an intermediate processing step.

11
12 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

13 This disclosure of the invention is submitted in furtherance of the
14 constitutional purposes of the U.S. Patent Laws "to promote the
15 progress of science and useful arts" (Article 1, Section 8).

16 This description of the present invention discloses embodiments of
17 various wireless communication devices. The wireless communication
18 devices are fabricated in card configurations (which include tags or
19 stamps) according to some aspects of the present invention. Certain
20 embodiments of invention are methods for producing wireless
21 communication devices such as remote intelligent communication devices
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(RIC) including radio frequency identification devices (RFID). The embodiments are illustrative only and other configurations in accordance with the invention are of course possible, with the invention only being limited by the accompanying claims appropriately interpreted in accordance with the Doctrine Of Equivalents.

Referring to Fig. 1, a remote intelligent communication device or wireless communication device 10 comprises part of a communication system 12. The remote intelligent communication device is capable of functions other than the identifying function of a radio frequency identification device. A preferred embodiment of the remote intelligent communication device includes a processor.

The communication system 12 includes an interrogator unit 14. An exemplary interrogator 14 is described in U.S. Patent Application Serial Number 08/806,158, filed February 25, 1997, assigned to the assignee of the present application and incorporated herein by reference. The wireless communication device 10 communicates via wireless electronic signals, such as radio frequency (RF) signals, with the interrogator unit 14. Radio frequency signals including microwave signals are utilized for communications in a preferred embodiment of communication system 12. The communication system 12 includes an antenna 16 coupled to the interrogator unit 14.

1 Referring to Fig. 2, the wireless communication device 10 includes
2 an insulative substrate or layer of supportive material 18. The term
3 "substrate" as used herein refers to any supporting or supportive
4 structure, including but not limited to, a supportive single layer of
5 material or multiple layer constructions. Example materials for the
6 substrate 18 comprise polyester, polyethylene or polyimide film having
7 a thickness of 4-6 mils (thousandths of an inch).

8 Substrate 18 provides a first or lower portion of a housing for
9 the wireless communication device 10 and defines an outer periphery 21
10 of the device 10. Substrate 18 includes a plurality of peripheral
11 edges 17.

12 Referring to Fig. 3, at least one ink layer 19 is applied to
13 substrate 18 in preferred embodiments of the invention. Ink layer 19
14 enhances the appearance of the device 10 and conceals internal
15 components and circuitry provided therein. A portion of ink layer 19
16 has been peeled away in Fig. 3 to reveal a portion of an upper
17 surface 25 of substrate 18. In other embodiments, plural ink layers are
18 provided upon upper surface 25.

19 A support surface 20 is provided to support components and
20 circuitry formed in later processing steps upon substrate 18. In
21 embodiments wherein at least one ink layer 19 is provided, support
22

1 surface 20 comprises an upper surface thereof as shown in Fig. 3.
2 Alternatively, upper surface 25 of substrate 18 operates as the support
3 surface if ink is not applied to substrate 18.

4 A patterned conductive trace 30 is formed or applied over the
5 substrate 18 and atop the support surface 20. Conductive trace 30 is
6 formed upon ink layer 19, if present, or upon substrate 18 if no ink
- layer is provided. A preferred conductive trace 30 comprises printed
8 thick film (PTF). The printed thick film comprises silver and polyester
9 dissolved into a solvent. One manner of forming or applying the
10 conductive trace 30 is to screen or stencil print the ink on the support
11 surface 20 through conventional screen printing techniques. The printed
12 thick film is preferably heat cured to flash off the solvent.

13 The conductive trace 30 forms desired electrical connections with
14 and between electronic components which will be described below. In
15 one embodiment, substrate 18 forms a portion of a larger roll of
16 polyester film material used to manufacture multiple devices 10. In
17 such an embodiment, the printing of conductive trace 30 can take place
18 simultaneously for a number of the to-be-formed wireless communication
19 devices.

20 The illustrated conductive trace 30 includes conductive lines and
21 patterns, such as an electrical connection 28, a first connection
22

1 terminal 53 (shown in phantom in Fig. 3) and a second connection
2 terminal 58. Conductive trace 30 additionally defines transmit and
3 receive antennas 32, 34 in one embodiment of the invention.
4 Antennas 32, 34 are suitable for respectively transmitting and receiving
5 wireless signals or RF energy. Transmit antenna 32 constitutes a loop
6 antenna having outer peripheral edges 37. Receive antenna 34
7 constitutes two elongated portions individually having horizontal
8 peripheral edges 38a, which extend in opposing directions, and
9 substantially parallel vertical peripheral edges 38b.

10 Other antenna constructions are of course possible. In particular,
11 both transmit and receive operations are implemented with a single
12 antenna in alternative embodiments of the present invention. Both
13 antennas 32, 34 preferably extend or lie within the confines of
14 peripheral edges 17 and outer periphery 21.

15 One embodiment of a wireless communication device 10 includes
16 a power source 52, an integrated circuit chip 54, and capacitor 55.
17 Power source 52, capacitor 55, and integrated circuit chip 54 are
18 provided and mounted on support surface 20 and supported by
19 substrate 18. The depicted power source 52 is disposed within transmit
20 antenna 32 of wireless communication device 10. Capacitor 55 is
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1 electrically coupled with loop antenna 32 and integrated circuit 54 in
2 the illustrated embodiment.

3 Power source 52 provides operational power to the wireless
4 communication device 10 and selected components therein, including
5 integrated circuit 54. In the illustrated embodiment, power source 52
6 comprises a battery. In particular, power source 52 is preferably a thin
7 profile battery which includes first and second terminals of opposite
8 polarity. More particularly, the battery has a lid or negative (i.e.,
9 ground) terminal or electrode, and a can or positive (i.e., power)
10 terminal or electrode.

11 Conductive epoxy is applied over desired areas of support
12 surface 20 using conventional printing techniques, such as stencil or
13 screen printing, to assist in component attachment. In accordance with
14 the present invention, the conductive epoxy is substantially conductive
15 even in the low-viscosity uncured form in which the epoxy is applied
16 to support surface 20. The conductive epoxy preferably has sufficient
17 conductivity that a 15 mil length sample of the liquid conductive epoxy
18 having cross-sectional dimensions of 50 mil by 2 mil would have a
19 resistance of less than about 100 ohms along its length while having a
20 viscosity of less than about 100,000 cps. The conductive epoxy can be
21 a mixture of a first liquid comprising a base epoxy and a second liquid
22

1 comprising a hardener. A suitable base epoxy is a silver-containing
2 epoxy sold under the product name 116-37A by Creative Materials, Inc.
3 of Tyngsboro, Massachusetts. A suitable hardener is sold under the
4 product name B187 by Creative Materials, Inc.

5 In accordance with one aspect of the present invention, the epoxy
6 will comprise an ionic salt. Preferably the ionic salt is soluble in at
7 least one of the first and second liquids. The ionic salt can comprise
8 organic salts and/or inorganic salts. The ionic salt can comprise, for
9 example, a lithium salt, such as a lithium imide salt. Suitable lithium
10 salts are, for example, LiAsF_6 and $\text{LiN}(\text{CF}_3\text{SO}_2)_2$.

11 The ionic salt can be present in one or both of the first and
12 second liquids. Alternatively, the ionic salt can be dissolved in a third
13 liquid, which is subsequently mixed with the first and second liquids.
14 The mixing of the third liquid with the first and second liquids can
15 occur prior to, or after, application of the epoxy to support surface 20.
16 Preferably, the first, second and third liquids are mixed prior to
17 application to support surface 20. More preferably, the ionic salt
18 comprises a lithium salt present in a third liquid to a concentration of
19 from about 0.5 molar to about 1.2 molar prior to mixing the third
20 liquid with the first and second liquids. The first, second and third
21 liquids are mixed in a ratio of from about 100:3.6:5 (base
22

1 epoxy/hardener/third liquid, by weight) to about 100:3.6:6 (base
2 epoxy/hardener/third liquid, by weight) to yield a final concentration of
3 ionic salt within the epoxy of from about 0.4% (by weight) to
4 about 2% (by weight). The epoxy is then applied to support
5 surface 20.

6 A suitable material for the third liquid is a thinner selected from
7 the group consisting of aliphatic glycidyl ethers and aromatic glycidyl
8 ethers. For example, the third liquid can comprise one or more
9 products marketed as Heloxy 61 and Heloxy 7 by Shell Chemical
10 Company of Houston, Texas.

11 The ionic salt within the epoxy enables the epoxy to become
12 conductive more rapidly than would occur in the absence of the ionic
13 salt. In accordance with the present invention, a 15 mil length sample
14 of epoxy 30 having cross-sectional dimensions of 50 mil by 2 mil has
15 a resistance of less than about 100 ohms along its length in less than
16 or equal to about 30 minutes from a time that a liquid mixture
17 comprising hardener, base epoxy and ionic salt is formed. More
18 preferably, the epoxy has such resistance of less than about 100 ohms
19 in a time of from about 10 minutes to about 20 minutes from when
20 a mixture of base epoxy, hardener and ionic salt is formed.
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22

1 If a mixture of base epoxy, hardener and ionic salt is formed
2 prior to providing the epoxy onto support surface 20, it will generally
3 take from 10 minutes to 30 minutes from a time the mixture is formed
4 to a time that the mixture is applied to support surface 20.
5 Accordingly, the mixture of the present invention is preferably
6 immediately suitably conductive (i.e., has a resistance less than 100 ohms
7 in the geometry specified earlier) upon mixing. Some reduction to
8 practice examples took up to ten minutes to achieve resistivity of less
9 than 100 ohms. Yet, it typically takes at least this amount of time
10 from the point of mixing until the epoxy is applied to a substrate. In
11 contrast, the above-discussed prior art epoxy mixtures, which take 1 to 2
12 hours to become conductive (sometimes with application of heat), are
13 not conductive when applied to a substrate.

14 The power source 52 is provided and mounted on support
15 surface 20 using the conductive epoxy. Integrated circuit 54 and
16 capacitor 55 are also provided and mounted or conductively bonded on
17 the support surface 20 using the conductive epoxy. Integrated circuit 54
18 can be mounted either before or after the power source 52 is mounted
19 on the support surface 20.

20 Integrated circuit chip 54 includes suitable circuitry for providing
21 wireless communications. For example, in one embodiment, integrated
22

1 circuit chip 54 includes a processor 62, memory 63, and wireless
2 communication circuitry or transponder circuitry 64 (components 62, 63,
3 64 are shown in phantom in Fig. 3) for providing wireless
4 communications with interrogator unit 14. An exemplary and preferred
5 integrated circuit 54 is described in U.S. Patent Application Serial
6 08/705,043, incorporated by reference above.

7 One embodiment of transponder circuitry 64 includes a transmitter
8 and a receiver respectively operable to transmit and receive wireless
9 electronic signals. In particular, transponder circuitry 64 is operable to
10 transmit an identification signal responsive to receiving a polling signal
11 from interrogator 14. In the described embodiment, processor 62 is
12 configured to process the received polling signal to detect a predefined
13 code within the polling signal. Responsive to the detection of an
14 appropriate polling signal, processor 62 instructs transponder circuitry 64
15 to output an identification signal. The identification signal contains an
16 appropriate code to identify the particular device 10 transmitting the
17 identification signal in certain embodiments. The identification and
18 polling signals are respectively transmitted and received via
19 antennas 32, 34 of the device 10.

20 First and second connection terminals 53, 58 are coupled to the
21 integrated circuit 54 by conductive epoxy in accordance with a preferred
22

embodiment of the invention. The conductive epoxy also electrically connects the first terminal of the power source 52 to the first connection terminal 53. In the illustrated embodiment, power source 52 is placed lid down such that the conductive epoxy makes electrical contact between the negative terminal of the power source 52 and the first connection terminal 53.

Power source 52 has a perimetral edge 56, defining the second power source terminal, which is provided adjacent second connection terminal 58. In the illustrated embodiment, perimetral edge 56 of the power source 52 is cylindrical, and the connection terminal 58 is arcuate and has a radius slightly greater than the radius of the power source 52, so that connection terminal 58 is closely spaced apart from the edge 56 of power source 52.

Subsequently, the conductive epoxy is dispensed relative to perimetral edge 56 and electrically connects perimetral edge 56 with connection terminal 58. In the illustrated embodiment, perimetral edge 56 defines the can of the power source 52. The conductive epoxy connects the positive terminal of the power source 52 to connection terminal 58. The conductive epoxy is then cured. Thus, the integrated circuit and battery are conductively bonded relative to the substrate and to the conductive lines of trace 30. In a preferred embodiment of the

1 invention in which the epoxy is conductive prior to provision of power
2 source 52 and integrated circuit 54 onto support surface 20, there will
3 not be the gradual build-up of conductivity described above in the
4 "background" section of this disclosure. Accordingly, the epoxy of the
5 present invention can alleviate the latch-up problems described above in
6 the "background" section of this disclosure.

7
8 An encapsulant, such as encapsulating epoxy material, is
9 subsequently formed following component attachment. In one
10 embodiment, the encapsulant is provided over the entire support
11 surface 20. Such encapsulates or envelopes the antennas 32, 34,
12 integrated circuit 54, power source 52, conductive circuitry 30,
13 capacitor 55, and at least a portion of the support surface 20 of
14 substrate 18. Such operates to insulate and protect the components
15 (i.e., antennas 32, 34, integrated circuit 54, power source 52, conductive
16 circuitry 30 and capacitor 55).

17 Experiments have been conducted to compare conductivities of
18 epoxy mixtures of the present invention with epoxy mixtures of the prior
19 art lacking ionic salts. Such experiments indicate the epoxy mixtures
20 of the present invention have conductivities which are several orders of
21 magnitude higher than prior art epoxy mixtures under low viscosity
22 conditions. An example epoxy of the present invention is as follows.

EXAMPLE

A liquid epoxy mixture was formed by combining 100 parts of a silver-containing epoxy (116-37A from Creative Materials, Inc.) with 3.6 parts of a curing agent (B-187 from Creative Materials Inc), and with 5 parts of a LiAsF_6 solution (0.65 grams LiAsF_6 in 3 ml of Heloxy 61 - the Heloxy 61 was from Shell Chemical Co.). A 15 mil length sample of the liquid conductive epoxy mixture having cross-sectional dimensions of 50 mil by 2 mil had a resistance of less than about 100 ohms along its length within about 10 minutes of forming the mixture. Also, a 15 mil length sample of the liquid conductive epoxy mixture having cross-sectional dimensions of 50 mil by 2 mil had a resistance of less than about 100 ohms along its length while having a viscosity of less than about 100,000 cps.

In compliance with the statute, the invention has been described in language more or less specific as to structural and methodical features. It is to be understood, however, that the invention is not limited to the specific features shown and described, since the means herein disclosed comprise preferred forms of putting the invention into effect. The invention is, therefore, claimed in any of its forms or

1 modifications within the proper scope of the appended claims
2 appropriately interpreted in accordance with the doctrine of equivalents.
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